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ATTACK AND BROOD SURVIVAL BY THE DOUGLAS-FIR BEETLE IN FOUR TYPES OF WINDTHROWN TREES IN WESTERN WASHINGTON

by

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INTRODUCTION

Large amounts of timber were windthrown in western Washington in the fall of 1958. Although salvage operations began immediately, much of the Douglas-fir blowdown became infested with the Douglas-fir beetle (Dendroctonus pseudotsugae Hopk.) before it could be removed from the woods. It became apparent that much of the timber could not be salvaged before broods of beetles in the trees emerged in the spring of 1960 -- thus offering a serious threat to green timber. Accordingly, the question arose as to whether some types of windthrow were more apt to increase the beetle populations than others; if so, logging the down trees with greatest brood potential might reduce the hazard. In an attempt to help answer this question, and to obtain basic information on the beetles' habits in windthrow, the study described in this report was undertaken.

The study was carried out in the fall of 1959 and spring of 1960 on three Weyerhaeuser Company tree farms -- Vail, McDonald, and St. Helens. It was a cooperative undertaking with entomologists of the Pacific Northwest Forest and Range Experiment Station. In

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order that findings from the study could be used as soon as possible by field foresters, a preliminary report was issued in October, 1959 (Johnson, Orr and Wright). The present paper describes in more detail the methods and results of the study, and includes data collected in the spring of 1960.

Objective

The objective of the study was: To determine the relative intensity of attack and brood survival of Douglas-fir beetle in windthrow of 4 types: Shaded old growth, exposed old growth, shaded second growth, and exposed second growth. The original plan called for an evaluation of additional categories of blowdown such as those broken off at various heights and those whose roots were still functioning, at least in part. However, satisfactory replications could not be found of these categories.

REVIEW OF LITERATURE

It is well known that windthrown Douglas-fir is highly attractive to the Douglas-fir beetle. Wright and Lauterbach (1958) demonstrated clearly the marked increase of tree-killing following blowdown and the rapid decrease when windthrown material was no longer available to maintain the beetle populations. Furniss (1959) states that salvage of windthrow soon after it is infested will reduce the chance of beetle buildup. Also, he recommends removal of the infested logs before the bark loosens to insure that the beetles are actually removed from the forest. Walters (1956) is of the opinion that in the interior of British Columbia tree-killing by the Douglas-fir beetle is primarily associated with logging operations. McCowan and Rudinsky (1958) point out that timber felled in the course of road construction also provides the beetles with an excellent opportunity to maintain high population levels. Trees weakened by fire and insect defoliation also are preferred for attack by Douglas-fir beetle (Furniss, 1936; Evenden and Wright, 1955).

High subcortical (beneath-the-bark) temperatures encountered in logs exposed to direct sunlight are often fatal to bark beetle broods. Miller (1931) in studies of the western pine beetle found that complete mortality occurred when the subcortical temperatures reached 120° F. Lethal bark temperatures may occur when the air temperature is as much as 40° F. lower. In thin-barked trees, exposure to direct sunlight has been effective in control of the mountain pine beetle (Patterson, 1931). McCowan and Rudinsky (1958) report that trees or logs exposed to direct sunlight show heavy Douglas-fir beetle brood mortality. Aside from the direct effect of high temperature, broods may be killed because logs exposed to direct sunlight become dry and thus unsuitable for food.

Geiger (1957) reviewed some of the early work of European workers concerning microclimate variation on the surface of fallen logs

and its effect on mortality of broods of Ips typographus. It was shown that bark temperatures of 122° F. were reached when the surrounding air temperature 40 inches from the log was only 86° F. On the segment of logs most exposed to sun, no eggs were laid by the bark beetle. Eggs were deposited on the immediately adjacent areas but they did not produce brood because of the dry cambium. Broods developed on the sides and bottom of the logs, but those on the bottom were later killed by excessive moisture.

METHODS OF STUDY

On each of the 3 study areas, 8 trees in each of the following classes were selected: (1) Second growth shaded, (2) second growth exposed, (3) old growth shaded and (4) old growth exposed. Four trees in each class were then selected at random for sampling. Second growth was defined as being less than 160 years; and old growth over 160 years. Actually, few second growth were more than 100 years and all old growth were over 300 years. Shaded trees were those that were protected from the direct rays of the sun for most of the day.

Three 16-foot logs were chosen from each tree for sampling -- one each at the butt, midbole, and top. The bottom of the butt log began at stump height of 2 feet; the top log was defined as that 16-foot section below a point where the diameter outside bark was 40 per cent of dbh. On each 16-foot log, the exact sampling point was chosen at random and a distance of 1.6 feet measured longitudinally each way from the point. This gave a sample 3.2 feet long, which is approximately 20 per cent of the bark area of a 16-foot log.

On second growth, a hand saw was used to make parallel saw cuts at each end of the sample area. A power saw was used to make the cuts on the thicker-barked old growth. The cuts were made as far around the log as possible. Bark spuds were then used to peel the 3.2-foot section around the log. The diameter inside bark and the bark thickness were measured at the mid point of the sample. The upper 1/3 of the log was designated top; the remainder of the circumference was termed "side".

The following information was taken on each sample: (1) Number of successful galleries on top and sides, (2) Number of aborted galleries on top and sides (an aborted gallery was one in which no larvae were produced), (3) Number of ambrosia beetle entrance holes (genera Trypodendron and Gnathotrichus) on a 1-square-foot sample on the top and sides, and (4) Number of flathead and round-headed borer larvae (families Buprestidae and Cerambycidae) per square foot.

On one Douglas-fir beetle gallery selected at random from the top and one from the side the following information was recorded:

(1) Total length of egg gallery, (2) Total number of larval tunnels, (3) Number of live progeny -- i.e., living larvae, pupae or adults, and (4) Number of parasitic and predaceous insects (genera Coeloides, Medetera and Enoclerus).

In the spring of 1960, the 26 study trees remaining in the woods were resampled by taking a side gallery at each sampling position and recording the same information as above.

In arranging the data for analysis of variance, the survival rate was calculated by assuming 10 eggs were laid per inch of gallery, as reported by McCowan and Rudinsky (1958). Survival ratios were computed by dividing the number of successful progeny by the length of brood gallery x 10. This value multiplied by 100 gave per cent survival. The average attack density per square foot was computed by calculating the number of square feet of bark area on the top and sides and dividing the total gallery count by this figure.

RESULTS

Tree characteristics

Table 1 presents some of the important characteristics of the sample trees. Attention is drawn to the considerable size difference between old growth and second growth.

Table 1. Characteristics of sample trees

Age, exposure class, and number	Ave. dbh	Ave. height	Scribner vol.	Ave. bark thickness			Ave. sample size
				Butt	Mid-bole	Top	
	in.	ft.	fbm	in.			sq. ft.
Old growth shaded (12)	60	211	8,100	2.0	1.6	1.3	37.5
Old growth exposed (12)	51	198	5,700	2.3	1.6	1.1	35.7
Second growth shaded (12)	25	150	910	0.9	0.6	0.4	21.7
Second growth exposed (12)	26	149	960	0.9	0.5	0.4	19.9

Number of attacks

Table 2 shows the number of successful attacks per square foot by age and exposure classes. There is a significant difference, at the 1 per cent level, in the number of successful attacks by exposure class, but there is no significant difference by age class. These data show that exposed trees were not as heavily attacked as those in the shade.

There was no significant difference in the number of aborted attacks by age or exposure. However, the ratio of aborted attacks to successful ones was greater in the exposed logs.

Table 3 shows the number of attacks per square foot at the various sampling positions. There were significantly greater number of attacks on the sides than on the upper surface of the logs. There was also a significant difference in number of attacks at the butt, midbole, and top log positions, with the greatest number occurring toward the top.

Table 2. Successful Douglas-fir beetle attacks per square foot by age and exposure classes

Age class	Exposure class		Average
	exposed	shaded	
	Number		
Old growth	0.53	0.73	0.63
Second growth	0.43	1.00	0.71
Ave.	0.48	0.87	0.67

Table 3. Successful attacks per square foot by sampling position

Log position	Log face		Average
	upper	side	
	Number		
Butt	0.36	0.55	0.45
Midbole	0.52	0.85	0.68
Top	0.64	0.88	0.76
Ave.	0.51	0.76	0.63

Brood survival

Table 4 shows per cent survival as related to exposure, age, and sampling position. Survival differed significantly with exposure and age, the more exposed second growth logs having the lowest survival. There was no significant difference in survival between sampling positions along the tree. However, there was a significant difference between sampling faces in that survival was less on the upper surface of the logs than on the sides.

Table 4. Survival of Douglas-fir beetle broods by age, exposure, and sampling position

Age and exposure class	Sampling position and face						Average
	Butt		Midbole		Top		
	upper	side	upper	side	upper	side	
	Per cent						
Second growth							
exposed	9.7	21.9	5.0	18.1	8.2	12.8	12.63
shaded	34.3	39.8	35.8	33.1	31.4	32.8	34.54
Old growth							
exposed	28.6	40.4	27.0	19.2	17.9	18.0	25.19
shaded	43.3	50.8	30.9	38.3	25.2	39.4	37.98
Ave.	28.96	38.22	24.69	27.17	20.68	25.77	27.58

As mentioned in the methods of study section, 26 of the original 48 study trees remained unlogged until the spring of 1960; these were resampled. There was a highly significant difference in the brood survival in the fall as compared with spring (Table 5). Survival dropped from 31 to 19 per cent over winter. The interactions of years with exposure and age were not significant, showing that shaded logs still produced significantly more beetles than exposed ones after overwintering.

Much of the overwintering mortality was evidently due to drowning in the excessively moist inner bark. At the time of the spring examination, many of the larvae, pupae, and callow adults were abnormally flaccid or turgid, suggesting they had been killed by

a disease. Dr. E. A. Steinhaus of the University of California Laboratory of Insect Pathology examined samples of the affected larvae and pupae but found only saprophytic fungi, yeasts, and bacteria.

Table 5. Comparison of brood survival in side galleries of 26 trees -- fall 1959 and spring 1960 evaluations

Year	Old growth exposed	Old growth shaded	Second growth exposed	Second growth shaded	Average
	Per cent				
1959	26.3	42.2	17.9	37.4	30.7
1960	13.0	30.8	10.6	21.7	18.8
Ave.	19.7	36.5	14.2	29.6	24.8

To determine whether tree age, exposure, and sampling position influenced mortality of eggs and early instar larvae, an analysis was made of the number of larval tunnels 1 inch long or longer (successful) as compared to the number of eggs laid (Table 6). The analysis assumed an average of 10 eggs per inch of gallery. Results (Table 6) show a significant difference between log faces, with larvae on the upper face having the poorest success. There was also a significant difference by ages with the highest success in the old growth trees.

Table 6. Success of early-instar larvae as influenced by age, exposure and position of sample

Age and exposure classes	Sample position and face: Butt upper	Butt side	Midbole upper	Midbole side	Top upper	Top side	Average
	Per cent						
Second growth exposed	47.1	73.7	47.7	63.8	59.4	71.8	60.6
shaded	65.2	66.7	72.9	71.6	65.9	70.2	68.8
Old growth exposed	74.8	85.4	69.9	75.1	71.9	68.3	74.2
shaded	82.6	82.0	77.1	77.0	74.1	87.3	80.0
Ave.	67.4	77.0	66.8	71.9	67.8	74.4	70.9

Gallery length

No significant difference was found in gallery length between ages or exposure to sunlight. However, there was a significant difference due to position on the tree -- the shortest galleries occurring on the upper surface of the top log (Table 7).

Table 7. Parent gallery length as related to sampling position

Log position	Face: top	Face: side	Average
	inches		
Butt	8.95	9.28	9.11
Midbole	10.31	8.88	9.60
Top	6.52	9.48	8.00
Ave.	8.59	9.21	8.90

Other insects

The following information on other insects is included as a matter of supplemental interest to show how the attack densities of various species of insects differ in respect to age class, exposure class, and sampling position.

Three species of ambrosia beetles were encountered. These were Trypodendron lineatum Oliver, Gnathotrichus sulcatus LeConte and Xyleborus saxeseni Ratz. The last species was present only in a few logs. A summary of attacks per square foot, by age and exposure, is given in Table 8. There was a significantly greater number of Gnathotrichus attacks in old growth trees. Trypodendron attacks did not vary significantly between second and old growth, but exposure was significant -- the greater number of attacks occurred in shaded logs.

Table 8. Ambrosia beetle attacks per square foot in windthrown Douglas-fir trees by age and exposure

Age of tree	Exposure: exposed: Gnatho.	Exposure: exposed: Trypo.	Exposure: shaded: Gnatho.	Exposure: shaded: Trypo.	Average: Gnatho.	Average: Trypo.
	Number					
Second growth	0.7	0.1	0.5	1.7	0.6	0.8
Old growth	2.2	0.6	2.4	4.2	2.3	2.1
Ave.	1.4	0.3	1.3	2.8	1.4	1.4

The number of ambrosia beetle attacks by sampling position is shown in Table 9. Gnathotrichus attacks were significantly greater in the midbole position, but there was no difference between the top and side faces. Trypodendron attacks also varied by position but the heaviest attack was in the top log. Again, attack density did not vary between top and side faces.

Table 9. Ambrosia beetle attacks per square foot by sampling position

Position of log	Face: upper Gnatho.	upper Trypo.	side Gnatho.	side Trypo.	Average Gnatho.	Average Trypo.
	Number					
Butt	0.9	0.5	0.7	0.5	0.8	0.5
Midbole	1.9	1.4	2.3	1.7	2.1	1.6
Top	1.0	1.7	1.6	3.0	1.3	2.3
Ave.	1.2	1.2	1.5	1.6	1.4	1.4

The number of flathead (buprestid) borer larvae per square foot is shown in Tables 10 and 11. The species involved were not determined but Buprestis aurulenta L., B. langi Mann., B. rusticorum Kirby, and Melanophila drummondi Kirby are the buprestids that most commonly attack Douglas-fir in the study area. Attacks by buprestids varied significantly by exposure (heaviest on exposed trees) but no significant difference was detected between second growth and old growth. There was a significantly greater number of attacks per square foot on the top of the log and at the butt. The incidence of roundhead (cerambycid) borers also was recorded, but data were insufficient for analysis.

Table 10. Buprestid larvae per square foot in windthrown Douglas-fir by age and exposure

Age	Exposure: exposed	Exposure: shaded	Average
	Number		
Second growth	7.2	0.2	3.7
Old growth	3.6	0.1	1.8
Ave.	5.4	0.2	2.8

Table 11. Buprestid larvae per square foot by sampling position

Log position	Face: upper	Face: side	Average
	Number		
Butt	4.3	1.6	2.8
Midbole	2.9	1.4	2.1
Top	1.9	1.1	1.5
Ave.	3.0	1.4	2.2

Predators and parasites

The number of predaceous flies of the genus Medetera, beetles of the genus Enoclerus, and the hymenopterous parasite Coeloides brunneri Vier. were recorded in each gallery. However, there was insufficient range in numbers to analyse in detail. Coeloides were found almost exclusively in second growth trees and were most numerous in the exposed portions and near the top. This insect oviposits through the bark and thus is limited by the length of its ovipositor. This helps to explain the greater numbers in tops of the thin-barked second growth. Medetera were concentrated most heavily in the mid log section. Enoclerus was not present in sufficient numbers to examine for trend.

DISCUSSION

This research indicates that Douglas-fir beetles attack windthrown trees exposed to the direct rays of the sun about half as heavily as they do shaded trees; they produce about one-third as much brood per gallery. Thus, approximately six times as many beetles would be produced in the shaded trees.

Beetle broods in shaded trees tend to develop more slowly and consequently more overwinter in the larval stage. Beetles overwintering as larvae do not emerge in the spring as soon as those overwintering as adults. The question arises as to whether the late-emerging beetles pose a greater threat to living trees than those emerging early. Opinions vary on this point, and can only be reconciled by further study. In many studies of other bark beetles, it has been shown that trees become more susceptible and attractive to bark beetles later in the year (Merker 1956). The beetles are able to bore in faster when the weather is warmer (Rudinsky and Vite 1956) and they have less competition due to overcrowding (McCowan and Rudinsky 1958). This leads to the speculation that late-emerging beetles may be more important than the early ones.

It is concluded that removing infested trees that occur in shaded places, such as those falling into the stand along cutting lines or within the stand proper and road right-of-way logs, will be of greater value in reducing bark beetle populations than removing trees exposed to the direct rays of the sun. The present study, however, showed that some beetles were produced in all categories of windthrow. The desirability of removing all infested material from the woods as soon as possible is clear.

The damage caused by wood boring insects to recently killed timber is another reason for prompt salvage of dead trees. In the present study the number of ambrosia beetle holes per square foot of log surface was not great, but even a few holes reduce lumber grade appreciably, especially when high quality logs are involved.

Though valuable data were obtained in this case study, much research remains to be done before accomplishing the end objective: To relate beetle attacks and brood statistics in blowdown to infestation that develops in green timber. It would seem logical that the greater the brood production in blowdown, the greater will be the amount of timber killed. But this has not been verified. Investigations are needed of such variables as the types, condition and amount of blowdown; ratio between beetle emergence and attacks; condition of the green stand; vigor of the beetle population; and climatic conditions.

The present study represents a start in this direction. Brood statistics for a specific blowdown were obtained, using a sampling method arrived at empirically. The logical next step would be to record what happens to the green stand in the study areas. However, the scope of the present study did not permit an adequate survey of the locations and amounts of blowdown -- so that they could be related to subsequent tree mortality. Furthermore, salvage efforts in the study area will prevent further observations. It is hoped that future situations will allow continuous study from the time of blowdown to termination of any insect activity that might develop in adjacent green timber.

SUMMARY

Extensive windthrow in western Washington in the fall of 1958 was heavily attacked the following year by the Douglas-fir beetle, thus creating favorable conditions for a general beetle outbreak. Because the infested blowdown could not be salvaged promptly, it provided an opportunity for a case study of beetle attack and brood production in different kinds of windthrow. Besides obtaining basic information about the habits of the beetles, the study was aimed to aid forest managers in setting salvage priorities.

The study was undertaken in 1959 and 1960 and was a cooperative undertaking by entomologists of Weyerhaeuser Forestry Research Center and the Pacific Northwest Forest and Range Experiment

Station, U. S. Forest Service, Portland, Oregon. Study areas were located on the St. Helens, Vail, and McDonald Tree Farms. Intensity of beetle attack and number of new beetles produced were studied in four types of windthrown trees: old growth shaded, old growth exposed, second growth shaded, and second growth exposed. Data also were collected on the abundance of parasites and predators of the Douglas-fir beetle, and the presence of wood boring insects. Principal findings were:

1. Shaded blowdowns were more heavily attacked than exposed ones, but there was no significant difference in intensity of attack in old growth as compared to second growth.

2. Attacks were heavier on the sides of logs as compared to upper surface, and at the sampling positions near the top of the tree as compared to those near the butt.

3. There was no difference between age or exposure classes in the number of aborted attacks; however, the ratio of aborted attacks to successful ones was greater in the exposed than in the shaded class.

4. Brood survival per parent gallery differed significantly with both exposure and age. Highest survival occurred in the shaded old growth (38 per cent), followed by shaded second growth (35 per cent), exposed old growth (25 per cent), and exposed second growth (13 per cent). Although survival per gallery was slightly higher in shaded old growth, shaded second growth trees produced more beetles because they were more heavily attacked.

5. There was no significant difference in beetle survival between the sampling positions at the butt, midbole and top of the tree; however, the sides of the logs produced more beetles than the upper surfaces.

6. There was significant overwintering mortality of beetle broods, survival dropping from 31 per cent in the fall to 19 per cent in the spring. Much of the mortality appeared to be drowning.

7. Two species of ambrosia beetles caused significant damage in the down trees. One species, Gnathotrichus sulcatus, showed a preference for old growth trees. The other, Trypodendron lineatum, showed no age class preference but was significantly more abundant in shaded blowdown than exposed.

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Fig. 1. – Study methods. Left – removing bark from a beetle-infested tree with spuds. Right – Douglas fir beetle galleries in shaded second-growth windthrow.

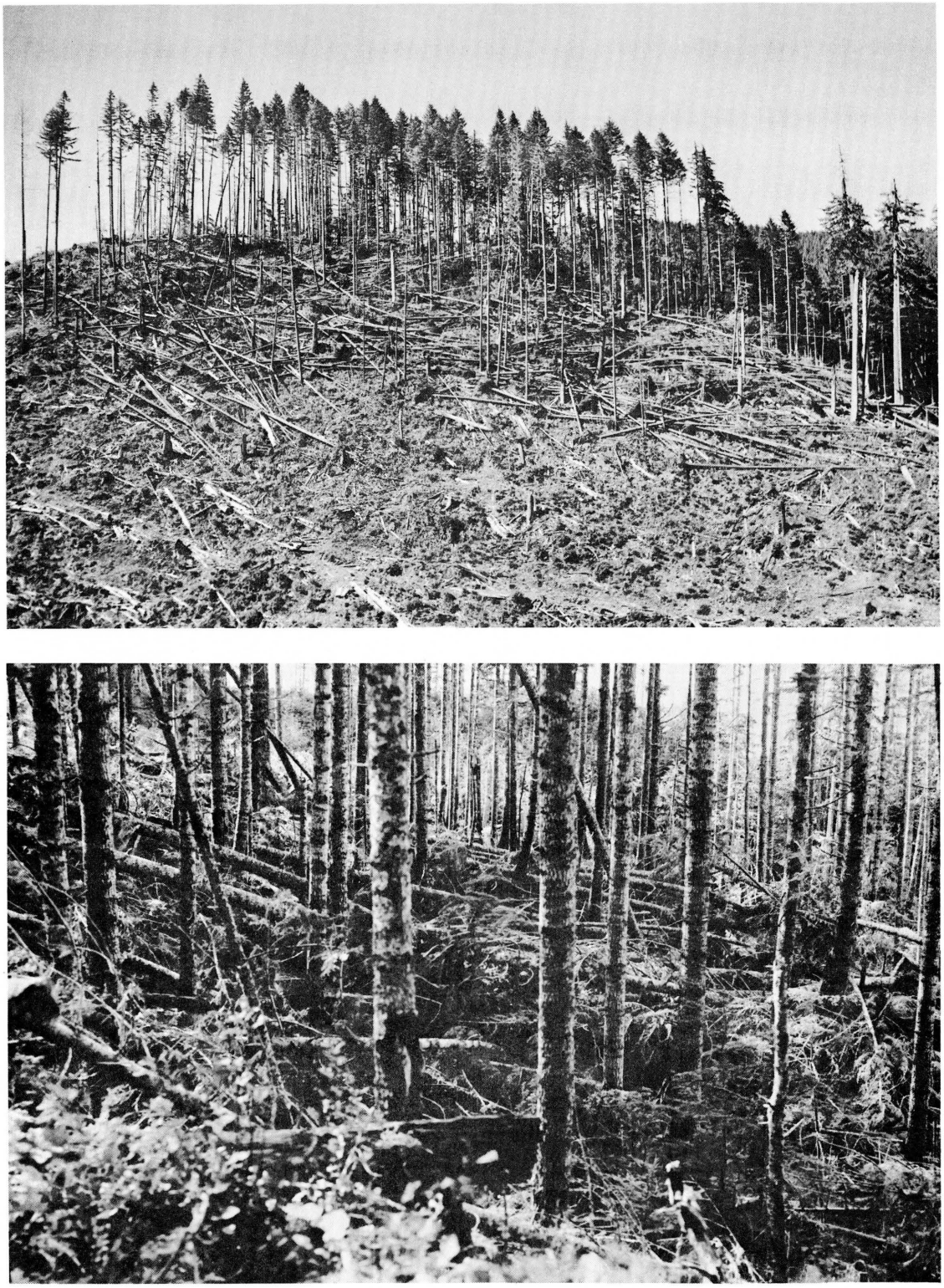

Fig. 2. – Heavy blowdown that occurred in the second-growth Douglas-fir on the McDonald tree farm. Exposed windthrow as shown in the upper photograph produces less beetles than shaded windthrow such as that shown in the lower photo.